NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 162

COMPLETE STUDY OF THE LONGITUDINAL OSCILLATION OF A VE-7 AIRPLANE

By F. H. NORTON and W. G. BROWN

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AERONAUTICAL SYMBOLS.

1. FUNDAMENTAL AND DERIVED UNITS.

	Symbol.	Metric.		English.	
		Unit.	Symbol.	Unit.	Symbol.
Length	l	meter	m.	foot (or mile)	ft. (or mi.).
Time	t	second	sec.	second (or hour)	sec. (or hr.).
Force	F	weight of one kilogram	kg.	weight of one pound	lb.
Power	P	kg.m/sec		horsepower	IP
Speed		m/sec	m. p. s.	mi/hr	M. P. H.

2. GENERAL SYMBOLS, ETC.

Weight, $W=mg$.

Standard acceleration of gravity, $g=9.806\text{m/sec.}^2=32.172\text{ft/sec.}^2$

Mass, $m=\frac{W}{g}$

Density (mass per unit volume), ρ

Standard density of dry air, 0.1247 (kg.-m.-sec.) at 15.6°C. and 760 mm. = 0.00237 (lb.-ft.-sec.)

Specific weight of "standard" air, 1.223 kg/m.^{3} = 0.07635 lb/ft.^{3}

Moment of inertia, mk^2 (indicate axis of the radius of gyration, k, by proper subscript)

Area, S; wing area, S_w, etc.

Gap, G

Span, b; chord length, c.

Aspect ratio $=b/c$

Distance from $c.\ g.$ to elevator hinge, f.

Coefficient of viscosity, μ.

3. AERODYNAMICAL SYMBOLS.

True airspeed, V

Dynamic (or impact) pressure, $q=\frac{1}{2}\rho V^2$

Lift, L; absolute coefficient $C_L=\frac{L}{qS}$

Drag, D; absolute coefficient $C_D=\frac{D}{qS}$.

Cross-wind force, C; absolute coefficient

$C_c=\frac{C}{qS}$.

Resultant force, R

(Note that these coefficients are twice as large as the old coefficients L_c, D_c.)

Angle of setting of wings (relative to thrust line), i_w

Angle of stabilizer setting with reference to thrust line i_t

Dihedral angle, γ

Reynolds Number $=\rho\frac{Vl}{\mu}$, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi/hr., normal pressure, 0°C: 255,000 and at 15.6°C, 230,000;

or for a model of 10 cm. chord, 40 m/sec., corresponding numbers are 299,000 and 270,000.

Center of pressure coefficient (ratio of distance of C. P. from leading edge to chord length), C_p.

Angle of stabilizer setting with reference to lower wing. $(i_t - i_w)=\beta$

Angle of attack, α

Angle of downwash, ϵ

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SUMMARY.

This investigation was carried out by the National Advisory Committee for Aeronautics at Langley Field in order to study as closely as possible the behavior of an airplane when it was making a longitudinal oscillation. The air speed, the altitude, the angle with the horizon and the angle of attack were all recorded simultaneously and the resulting curves plotted to the same time scale. The results show that all the curves are very close to damped sine curves, with the curves for height and angle of attack in phase, that for angle with the horizon leading them by 18 per cent and that for path angle leading them by 25 per cent.

INTRODUCTION.

The mathematical theory of dynamic stability is based upon numerous assumptions, such as a small oscillation and harmonic motion, and also it is usually assumed that the density and air speed are constant. As far as it is known there have been no actual tests made in flight to determine the exact behavior of an airplane when making oscillations. It was thought that data of this kind would be of considerable value in studying the theory of stability and would allow the visualization of the actual behavior of the machine.

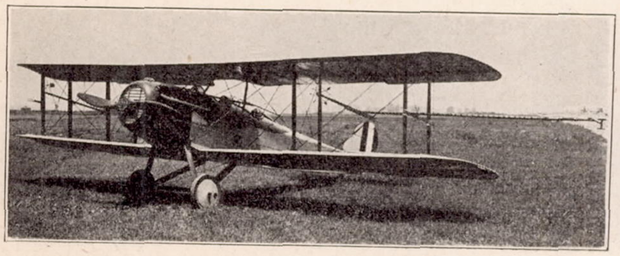

Fig. 1. Vought (VE–7) Airplane with recording apparatus.

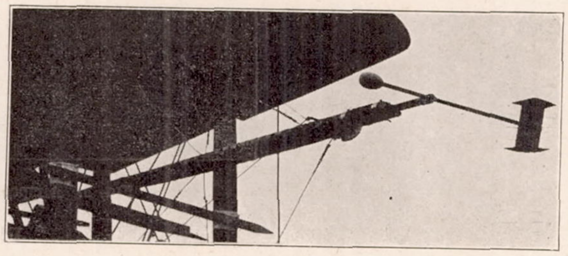

Fig. 2. Angle of attack Vane.

METHODS AND APPARATUS.

The airplane selected for this test was a standard VE–7 because of its excellent stability and smoothness of flight. The mean altitude of flight was 2,300 feet and the revolutions per minute about 1,150. The air speed was recorded with the National Advisory Committee for Aeronautics recording air speed meter connected to a swivelling pitot static head which had been previously carefully calibrated. The angle of inclination of the machine was measured by a kymograph which traced the image of the sun on a moving film. In order to get the actual angle of the machine the height of the sun was measured at the same time with a theodolite.

The height of the machine was recorded by a recording statoscope, which consisted of one of the standard National Advisory Committee for Aeronautics recording air speed meters connected on one side to a quart thermos bottle and on the other to a static head. Great care was taken to prevent leaks between the thermos bottle and the instrument, as even a slight leak here would introduce considerable errors. In order to prevent excessive pressure on the recording instruments there was a valve which could be opened to equalize the pressure until the altitude was reached for making the run.

The angle of attack was measured by an electrical instrument recently developed by the National Advisory Committee for Aeronautics consisting essentially of a vane on an outrigger (figs. 1 and 2) which extended about 6 feet beyond the wing tips and a recording instrument in

the cockpit. The vane was so located that it was very close to the Y axis of the airplane in order that an angular velocity in pitch would not introduce appreciable errors in the readings. It was also at such a distance from the wing tip that the interference with the wing was small.

Some of the original curves are reproduced in figure 3 to show how smooth and even was the motion. They are replotted, however, in figure 4 with their corresponding scales and are synchronized on the same time base. The computed curve of path angle is also included.

PRECISION.

A careful estimate of the probable precision in the four factors measured is given in the following table:

Air speed	±1.0 miles per hour.
Inclination of airplane	±0.5°.
Height	±2.0 feet.
Angle of attack	±1.0°.
Time	±0.25 seconds.

The angle of attack reading after steady flight was reached amounted to +7.5° while the inclination of the longeron was +1°, or +2.8° for the wings. This gives an installation error for the angle of attack vane of 4.7°, which was applied throughout.

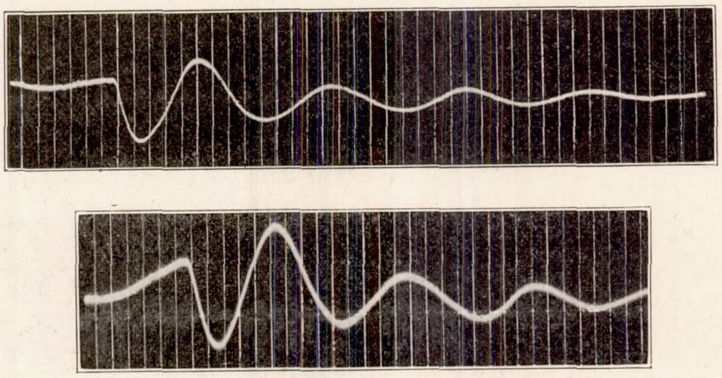

FIG. 3. Airspeed and statoscope records.

RESULTS.

The results are completely given in figure 4 where the quantities measured are plotted against a common time scale. The air speed plotted is indicated speed as no density correction was made.

As the exact time at which each curve reaches a maximum or minimum is of importance these times have been assembled in the following table which is more accurate than the curves.

Quantity.	Time to peaks in seconds.						
Air speed	+6.0	−19.0	+31.5	−45.0	+57.0	−71.5	+81.0
Inclination of airplane	−1.0	+14.0	−27.0	+41.5	−53.5	+64.5	−77.0
Height	−7.0	+21.0	−31.5	+47.0	−57.5	+71.0	−81.0
Angle of attack	−7.5	+19.5	−31.5	+47.5	−57.5	+69.5	−81.0
Angle of path	−13.5	+26.0	−36.0	+53.0	−64.0	+76.0	−88.5

+Indicates positive peak. −Indicates negative peak.

These figures show that the average period is 25 seconds, that the height and the angle of attack are in phase and the air speed in opposite phase, while the angle of inclination leads by 4.5 seconds or 18 per cent of the period, and the path angle by 6.3 seconds or 25 per cent of the period. It is also interesting to notice that the total energy of the airplane, which is made up of the kinetic and potential energy, remained practically constant throughout the oscillation.

The path angle was found by the difference between the angle of attack and the angle of inclination of the longerons, with 1.75 degrees subtracted for the incidence of the wings. This angle can also be found from the slope of the altitude curve plotted against distance rather than time and using true rather than indicated speed. A value was worked out for the $25\frac{1}{2}$-second station, giving a path angle of 4.5° as against 3.8° as deduced from the difference in angles, which shows a satisfactory agreement.

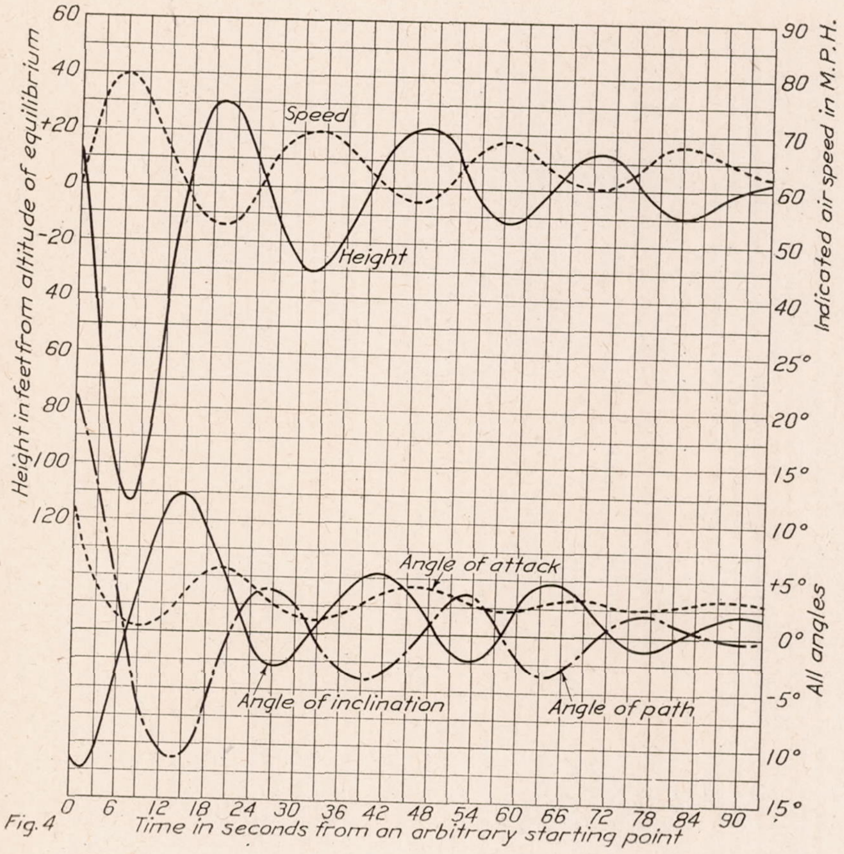

Fig. 4

CONCLUSIONS.

If the synchronized curves are assumed sinusoidal and plotted on an angle base, their phase relation may be summarized as follows:

Air speed	180°
Inclination of airplane	245°
Height	0°
Angle of attack	0°
Angle of path	90°

It is also shown that the angle of attack curve departs slightly from a sine curve, the upper peaks being sharper than the lower ones.

It is shown that the period and damping of an oscillation can be measured equally well from the air speed or the kymograph record.

In a future test of this kind it would be of interest to record the revolutions per minute and the slipstream velocity in order to obtain data on the propeller operation and the conditions at the tail.

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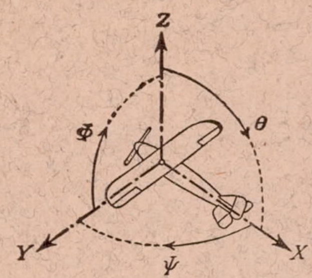

Positive directions of axes and angles (forces and moments) are shown by arrows.

Axis.		Force (parallel to axis) symbol.	Moment about axis.			Angle.		Velocities.	
Designation.	Symbol.		Designation.	Symbol.	Positive direction.	Designation.	Symbol.	Linear (component along axis).	Angular.
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_l=\frac{L}{q\,b\,S} \quad C_m=\frac{M}{q\,c\,S} \quad C_n=\frac{N}{q\,f\,S}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS.

Diameter, D
Pitch (a) Aerodynamic pitch, p_a
(b) Effective pitch, p_e
(c) Mean geometric pitch, p_g
(d) Virtual pitch, p_v
(e) Standard pitch, p_s
Pitch ratio, p/D
Inflow velocity, V'
Slipstream velocity, V_s

Thrust, T
Torque, Q
Power, P
(If "coefficients" are introduced all units used must be consistent.)
Efficiency $\eta = T\,V/P$
Revolutions per sec., n; per min., N
Effective helix angle $\Phi=\tan^{-1}\left(\frac{V}{2\pi r n}\right)$

5. NUMERICAL RELATIONS.

1 HP = 76.04 kg. m/sec. = 550 lb. ft/sec.
1 kg. m/sec. = 0.01315 HP
1 mi/hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi/hr.

1 lb. = 0.45359 kg.
1 kg. = 2.20462 lb.
1 mi. = 1609.35 m. = 5280 ft.
1 m. = 3.28083 ft.